Climatic or dietary change? Stable isotope analysis of Neolithic–Bronze Age populations from the Upper Ob and Tobol River basins

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Abstract:	The steppe and the forest-steppe zones of Siberia represent an environmental belt that links the outskirts of western Asia and Eastern Europe. This corridor of northern regions of steppe and forest steppe has contributed towards the dispersal of animal and crop species, metals, precious stones, as well as new technologies across Eurasia in prehistory (Kuz'mina, 2008; Koryakova and Epimakhov, 2007). Dietary changes within the populations inhabiting the southwest Siberia and northern Kazakhstan in prehistory indicate changes in the economy, at the same time marking the beginnings of East-West interaction across northern Eurasia. Past palaeodietary research using stable isotope analysis have mainly focussed on pastoral cattle breeding populations of the Bronze Age period. The introduction of domestic animal species of the near Eastern origin, such as sheep and goats, dramatically changed the lives of the local population. It is crucial, however, to access the diets of humans and animals from earlier periods (Neolithic/Chalcolithic) in order to understand the timing and nature of dietary change during the Bronze Age of southwest Siberia and northern Kazakhstan. It has been implied from previous research suggesting that elevated δ13C or δ15N values in animals and subsequently in humans, for example, could be a result of climatic rather than dietary change. In this paper we discuss the timing of pastoralism in the southern zones of western Siberia (Upper Ob River) and northern Kazakhstan (Tobol River basin) by presenting the stable isotope results of the Neolithic to Bronze Age humans and fauna. This data, combined with the AMS radiocarbon dating results, allows us to detect human dietary change through time

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Neolithic, Chalcolithic, Bronze Age, southwest Siberia, northern Kazakhstan, pastoralists, Stable isotopes

The steppe and the forest-steppe zones of Siberia represent an environmental belt that links the outskirts of western Asia and Eastern Europe. This corridor of northern regions of steppe and forest steppe has contributed towards the dispersal of animal and crop species, metals, precious stones, as well as new technologies across Eurasia in prehistory (Kuzmina, 2008; Koryakova and Epimakhov, 2007). Dietary changes within the populations inhabiting the southwest Siberia and northern Kazakhstan indicate changes in the economy, at the same time marking the beginnings of East-West interaction across northern Eurasia. Past palaeodietary research using stable isotope analysis have mainly focussed on pastoral cattle breeding populations of the Bronze Age period. The introduction of domestic animal species of the near Eastern origin, such as sheep and goats, dramatically changed the lives of the local population. It is crucial, however, to access the diets of humans and animals from earlier periods (Neolithic/Chalcolithic) in order to understand the timing and nature of dietary change during the Bronze Age of southwest Siberia and northern Kazakhstan. It has been implied from previous research suggesting that elevated $\delta^{13}C$ or $\delta^{15}N$ values in animals and subsequently in humans, for example, could be a result of climatic rather than dietary change.

In this paper we discuss the transition to pastoralism in the southern zones of western Siberia (Upper Ob River) and northern Kazakhstan (Tobol River basin) by presenting the stable isotope results of the Neolithic to Bronze Age humans and fauna. This data, combined with the AMS radiocarbon dating results, allows us to detect human dietary change through time within the region. Animal collagen results from different periods suggest that variations in human diet are primarily related to changes in human subsistence rather than climatic factors

1. Introduction

Understanding the timing and nature of transition from hunting and gathering to food production is of high importance for significantly changing the lifestyle of the local populations. The transfer of domesticated animals across Eurasia in prehistory reached thousands of kilometres away from the areas of their origin. The multi-

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directional translocation of pottery, metallurgy, raw materials and domesticated animals and plants between the western and the eastern fringes of Eurasia reflects the beginning of the global processes of interaction and exchange (Jones et al., 2011; Kohl, 2007; Linduff and Mei, 2009; Mei, 2003; Sherratt, 2005; Sherratt, 1996). It has been postulated that long distance connectivity and interaction across Eurasia only began to take place during the Bronze Age (Frachetti, 2012; Spengler III, 2015; Boivin et al., 2012). Zakh et al. (2010) and Kovalev (2011) have argued that the aridization of the climate around 5000 BP in the southwest Siberia lead to the expansion of the steppe ecological zone, activating the inflow of pastoralist communities from the south-west to further to north and east into former forest steppe regions. The earliest animal species of Near Eastern origin (sheep and goat) have been found in northern Kazakhstan and southwest Siberia in the sites of the Elunino Culture dated to the second half of the 3rd beginning of the 2nd mil. BC (Kiryushin et al., 2011). The remains of ovicaprids found in the Elunino settlements on the left side of Irtish River in northern Kazakhstan, such as Shiderty 10 and Shouke 1 (Merts, 2013). In the Upper Ob river basin of Russia the earliest ovicaprid bones are coming from the so-called Aleiskaya steppe region, from the settlement of Berezovaya Luka and Kolyvanskoe-I (analysed in this study) and dated to end of the 3rd – beginning of the 2nd mi. BC (Kiryushin et al., 2005; Kiryushin et al., 2011; Grushin, 2015). In the neighbouring Altai Mountains region the beginning of pastoralism is related to the Afanasevo Culture (Khazanov, 1994). The dating of this culture has been recently re-dated to 2900-2500 cal BC (Svyatko et al., 2009). However, to our knowledge, the remains of ovicaprids have been mainly found in several stratified settlement sites and none of the bones have been radiocarbon dated. Therefore, further research is required to place the ovicaprid remains from Altai within a reliable timeframe. In Central Kazakhstan the earliest evidence of sheep/goat-based pastoralism are coming from the Karagash human burial attributed to the Yamnaya Culture (2920-2712 cal BC) (Matuzeviciute et al., 2015), which contained both sheep skull and ribs that accompanied the deceased as a part of a ritual meal (Evdokimov and Loman, 1989). Finally, recent analysis of *Ovis* sp. from Inner Mongolia in China have demonstrated the earliest dates for Central Asia, estimated to be 4700-4400 cal BC (Dodson et al., 2014).

As the pathways and timing for the spread of ovicaprids and domestic cattle in southwest Siberia remains unclear, analysis of dietary change using stable isotope analysis allows the investigation of past human diets and dietary shifts at the individual level. While conducting stable isotope analysis, it is important to simultaneously analyse and compare both human and animal remains though time, as both the introduction of pastoralism and the onset of climatic changes can influence the stable isotope values of fauna and human bone collagen (see discussion below). Variation in $\delta^{13}C$ and $\delta^{15}N$ values between Neolithic/Chalcolithic and Bronze Age fauna would be an indicator of climatic factors and its influence on vegetation. Therefore, the similar shift in associated human stable isotope values though time would probably indicate a climatic rather than dietary change. On the other hand, if the fauna stable isotope data does not differ between periods, any observed change in humans though time can be linked with dietary change connected to the beginnings of pastoralism.

The aim of this paper is to study dietary change from the Neolithic though the Bronze Age period of populations from southwest Siberia and northern Kazakhstan. By analysing both human and animal remains using stable isotope analysis, we intend to establish if observed changes in human stable isotope ratios of bone collagen seen though time is caused by changes in diet or climate, and to subsequently identify the timing of the transition to pastoralism in the region.

2. Background

2.1 Archaeological background

The samples for research were collected from the region of the Upper Ob and Tobol River basins in southwest Siberia and northern Kazakhstan (Fig. 1). The samples used for this study from the Neolithic, Chalcolithic and Bronze Age periods. The Neolithic/Chalcolithic sites such as Itkul (Bolshoi Mys), Ust-Isha (Kiryushin, 2002; Kiryushin et al., 2000), Firsovo-XI (Kiryushin et al., 1994), Solontsy-5 (Kungurova, 2005) and Tuzovskie Bugry-I (Abdulganeev et al., 2000; Kiryushin and Kiryushin, 2015) are located in the southern part of western Siberia, in the Upper Ob river basin. The region is also called the "forest-steppe Altai". The Neolithic sites are attributed to the so-called Kuznetsko-Altaisky Neolithic (Kungurova 2005) and Bolshemysky Chalcolithic periods (Kiryushin 2002). The burial grounds of the Neolithic and Chalcolithic periods are small, often just consisting of a single burial; the Neolithic and Chalcolithic sites are located on rivers or steam banks and close to lakes. During the Bronze Age the size of burial grounds increases dramatically, as organization and complexity of the sacral space within society becomes noticeable (Kiryushin 2002). The Bronze Age settlements are mainly located close to multiple environmental niches such as hilly slopes, transition zones between steppe and forest steppe, and/or close to rivers, saline and fresh water lakes. The southwest Siberia site of Teleutsky Zvoz-I is attributed to the Early Bronze Age of the Elunino Culture, and the Firsovo-XIV site to the Middle Bronze Age of the Andronovo Culture (Fedorovo variant). The site of Novoilinovka from northern Kazakhstan is attributed to the Sintashta-Petrovka Culture of the Middle Bronze Age, while the Lisakovsk site in Kazakhstan is linked to the Andronovo Culture (Fedorovo and Alakul variant), which in northern Kazakhstan is attributed to the Late Bronze Age.

The Bronze Age period has been associated with significant transformations in the societies of the region, from fishing and hunting to pastoralism (Frachetti and Benecke, 2009; Kalieva and Logvin, 2011; Outram et al., 2012). Russian researchers link the changes that occurred in the early stage of the Bronze Age (second half of the 3rd millennium BC) with human migration from the West to the East, that brought not only domestic cattle (cattle, sheep, goats), but also bronze metallurgy (Kovalev, 2011). The excavated Early Bronze Age settlement of Berezovaya Luka, found at a depth of 2.5 m below the modern surface, contains the earliest evidence of sheep/goat in the region; the domesticated animals constitute 99% of all faunal remains (Kiryushin et al. 2005).

2.2 Previous palaeodietary studies in the region

Previous studies on the diet of southwest Siberia and northern Kazakhstan populations have mainly focused on the Bronze Age period. The only stable isotope studies reporting the diet of Neolithic populations are from the Preobrazhenka 6 site in Baraba forest-steppe region, reporting a human diet based on fish and C3 plants (Marchenko et al. 2015). Archaeological reports describe the Neolithic populations as hunter-gatherer mobile groups that relied heavily of the exploitation of fresh water resources and wild game (Molodin et al., 2012; Motuzaite-Matuzeviciute, 2012; Okladnikov, 1959). Attempts to identify domesticated plants in southwest Siberia and northern Kazakhstan prior to the Early Iron Age have not been successful to date (Kislenko and Tatarintseva, 1999; Korobkova, 1987). The Chalcolithic period in northern Kazakhstan in particular is linked with some dietary changes, mainly due to the local domestication of wild cattle in the Tersek Culture (Kalieva and Logvin, 2011) and horses in the Botai Culture (Outram et al., 2009; Zaibert, 1993) dated to the second half of the 4th mil. BC. Stable isotope analysis was conducted on two Chalcolithic individuals from northern and central Kazakhstan (Botai and Karagash) (Matuzeviciute et al., 2015; O'Connell et al., 2003). However, the sample size is too small to make any conclusion on the diet of the Chalcolithic population from these two individuals alone.

More studies on population diet exist for the Bronze Age period of the region. We know that fish was also important in the Bronze Age period to the populations across the steppe and forest-steppe zones, as indicated by the fish bones discovered in Bronze Age sites (Molodin et al., 2012; Motuzaite-Matuzeviciute, 2012). The consumption of fish among the forest steppe and steppe populations of Central Asia and Siberia is also interpreted from the stable isotope analysis seen in the elevated $\delta^{15}N$ values (Lightfoot et al., 2014; O'Connell et al., 2003; Ventresca Miller et al., 2014). In combination with published zooarchaeological data (eg. Frachetti and Benecke 2009; Kalieva and Logvin 2011; Outram et al. 2012), stable isotope analysis conducted in the region under study indicates Bronze Age diets based mainly on cattle and domesticated animal meat and milk (Katzenberg et al., 2012; Marchenko et al., 2015; O'Connell et al., 2003; Privat et al., 2006; Privat, 2004; Ventresca Miller et al., 2014). Some dietary contribution of C_4 plants is detectable in both fauna and human diets (Lightfoot, et al., 2014; Ventresca Miller, et al., 2014). The elevated $\delta^{13}C$ values in humans can be linked with millet crop consumption (beginnings of agriculture) (Svyatko et al., 2013). Archaeobotanical investigations conducted at the Middle Bronze Age sites of Kamenyi Ambar (Sintashta-Petrovka) in the Ural region of Russia, however, report large quantities of *Chenopodium album* seeds that were probably eaten by the local populations, but no evidence of domesticated crops were found (Rühl et al., 2015). We can conclude that no cereal crops confirmed by AMS dating have been reported from the Bronze Age in the whole southwest Siberia or northern Kazakhstan to date.

2.3 Climate, vegetation and geological baseline

Southwest Siberia encompasses numerous environmental niches. The vegetation across this territory represents a mosaic landscape that consists of forest steppe and steppe vegetation with varying proportions of C4 grasses, where hilly slopes, river beds, and both saline and fresh water lakes all carry a range of unique vegetation varieties. The vegetation on river bottoms and on lakeshores differs from those found on plateaus or highlands (Spengler III et al., 2013).

It is important to understand the past climatic variation between the Neolithic though the Bronze Age in the territory of southwest Siberia, as changes in vegetation types or an increase in salinity or humidity can leave an isotopic signature in both animal and human bone collagen (see below). Furthermore, climatic changes might influence changes in vegetation cover, significantly shifting the forest-steppe and steppe boarders (Krivonogov et al., 2012).

The Neolithic period in the southwest Siberia correlates with regional aridisation around *ca.* 5700-4300 BC, dense boggy vegetation formed in the drying lakes and river banks (Zakh et al., 2010). The environmental conditions in southwest Siberia changed during the middle Atlantic period *ca.* 4300-3300 BC with a progressive increase in humidity. The forest-steppe vegetation expanded further south to the Tobol-Ishim River basins. A new progressive shift towards aridity was recorded at *ca.* 3100-3000 BC with the southern steppe expanding further north (Zakh et al., 2010). Palynological studies in the Tobol-Ishim River and Upper Ob river basins show an arid climate during the *ca.* 2500-1200 BC or second half of the 3rd mil. BC- end of the 2nd mil. BC, that significantly affected a change in regional vegetation cover and the expansion of grassland, with the forest-steppe being replaced by semi-arid steppe (Zakh et al., 2010; Kiryushin, 2002). Periods of abrupt aridisation, increases in summer temperatures and decreases in winter temperature around 2800-2000 BC in the Eurasian steppe, have also been noted by other scholars (Kremenetski, 2003; Kremenetski et al., 1999) or around 2600-2300 cal BC (Shishlina et al., 2009). In the floodplains and valleys of the larger rivers the conditions persisted in a stable and favourable form (Zakh et al. 2010). This roughly is the period of transition to the Bronze Age and the beginning of pastoralism in the region under study.

2.4 Stable isotope methodology

Past human diets can be reconstructed by analysing bone chemistry, as the food that animals and humans eat is incorporated into their body tissues. For dietary analyses, the most important stable isotopes are those of carbon and nitrogen. Stable carbon isotope measurements (expressed as $\delta^{13}C$) can distinguish between diets based on plants using two photosynthetic pathways, C_3 and C_4, and between diets based on marine and terrestrial foods (Lee□Thorp, 2008; Schoeninger and DeNiro, 1984; Vogel and Van der Merwe, 1977). Studies have shown that the carbon isotope values of C_3 plants can be higher if plants are growing in water-stressed environments (Flohr et al., 2011). That means that climate change and rising temperatures can affect the $\delta^{13}C$ ratios of plants, and therefore could affect the stable isotope values of animals consuming these plants. The faunal carbon isotopic values in southwest Siberia could be elevated as a result of C_4 plants in the animals' diets that today represent a minor component of the flora in the steppe (Iacumin et al., 2004; Makarewicz and Tuross, 2006; Winter, 1981). The proportion of C4 to C3 plants very much depends on the aridity of the climate, with the drier regions having more C4 plants (Tieszen et al., 1979). An increase in aridity and an elevation of salinity can often result in the dominance of C4 grasses that can tolerate saline soils (climatic factors) (Collins and Jones, 1986). This will result in elevated $\delta^{13}C$ values in both animals and subsequently in humans that exist in this ecosystem.
Nitrogen isotope ratios (expressed as $\delta^{15}N$) reflect the trophic level of animal and humans, where consumers at higher trophic levels have higher $\delta^{15}N$ values (Hedges and Reynard, 2007). The nitrogen isotope ratios of freshwater (and marine) fish are elevated compared to terrestrial mammals, as aquatic ecosystems tend to have long food chains (Richards and Hedges, 1999; Schoeninger and DeNiro, 1984; Schoeninger et al., 1983). Nitrogen isotope ratios can also be affected by various environmental or climatic factors. Animals grazing on saline soils (Heaton, 1987; Britton et al., 2008) or living in arid environments (Ambrose and Sikes, 1991; Heaton, 1987; Hollund et al., 2010; Schwarcz et al., 1999) have higher nitrogen isotope values compared to animals grazing in other environments. It has been shown, for example,

that aridity played a role in the high nitrogen values of the Gansu humans in China (Liu et al., 2014). Recent research has identified differences between herbivores based on environmental niches, with higher $\delta^{13}C$ and $\delta^{15}N$ values characteristic of animals grazed in marshy areas (Britton et al., 2008). The $\delta^{15}N$ value in soil also will be elevated if it was fertilised with animal dung (Bogaard et al., 2007; Fraser et al., 2011). Finally, suckling animals and humans have elevated $\delta^{15}N$ values, because they are a trophic level higher than their mothers (Fogel, et al., 1997).

It will be important to keep all these factors that can affect both $\delta^{13}C$ and $\delta^{15}N$ values in mind while analysing human and faunal stable isotope data from the Neolithic though Bronze Ages of southwest Siberia and northern Kazakhstan.

3. Material and methods

3.1 *Stable isotope analysis*

Samples from 85 human and 96 animal bones from 17 sites from the southern part of western Siberia are presented in this paper together with published data from the northern Kazakhstan region (Fig. 1, SOM 1a,b). The sites are distributed in the present steppe-forest steppe belt that contains a variety of environmental niches. However, it is hard to imagine that humans and animals will remain living only in one environmental niche throughout their lifetime. Most likely they are moving though different environmental zones (Frachetti, 2008; Shishlina et al., 2009); therefore, the isotopic signals in studied individuals of both fauna and humans would be averaged out.

Bone samples were obtained from three institutions: Altay State University (Russia), Novosibirsk State University (Russia), the Institute of Archaeology in Karaganda (Kazakhstan) and Kostanai University (Kazakhstan). Animal bones were not available from every site from which human remains were obtained. It was attempted to collect faunal samples from the closest possible proximity to the analysed humans.

Collagen was extracted following the standard method of the Dorothy Garrod Laboratory, at the Department of Plant Sciences, Institute for Archaeological Research at the University of Cambridge, UK. In total of 500 mg of bone were obtained from each sample and the surfaces of the bone pieces were then cleaned by sandblasting. Bones were demineralized in 0.5 M aq. HCl at 4°C for up to ten days, changing the acid as necessary, and after rinsing three times with distilled water, were gelatinized in an acidic solution (pH 3) at 75 °C for 48 h. The liquid fraction containing the gelatinised protein was filtered off using an Ezee filter (Elkay Products) and freeze-dried. Triplicate samples of approximately 0.8 mg were used for each analysis in the Godwin Laboratory, University of Cambridge, using an automated elemental analyser (Costech, Valencia CA) coupled in continuous flow mode to a Thermo Finnigan Delta V isotope ratio-monitoring mass spectrometer (Bremen, Germany). Stable isotope concentrations are reported relative to the internationally defined VPDB standard for carbon, and AIR for nitrogen (Hoefs, 1997). Based on replicate analyses of international and laboratory standards, measurement errors are <0.1% for $\delta^{13}C$ values and 0.2% for $\delta^{15}N$ values.

The choice of statistical tests was based on the main goal of this paper, to see if there are any dietary differences between human and animal population from the Neolithic, Chalcolithic and Bronze Age periods. Statistical analyses were performed using R version 3.2.2. Samples were tested for normality using Student's t-test. The statistical significance levels is considered to be $p < 0.05$.

3.2 *AMS dating*

A total of 10 adult human bone samples were subject to accelerator mass spectrometer (AMS) ^{14}C dating (Table 1). All samples were prepared at the CHRONO Centre for Climate, the Environment, and 14Chronology, Queen's University Belfast. The routine bone pre-treatment procedure of the CHRONO laboratory involved a simple ABA treatment followed by gelatinization (Longin, 1971) and ultrafiltration (Brown et al., 1988) using a Vivaspin® filter cleaning method introduced by (Bronk Ramsey et al., 2004). The prepared collagen was sealed under vacuum in quartz tubes with an excess of copper oxide (CuO) and combusted at 850°C □to produce carbon dioxide (CO_2). The CO_2 was converted to graphite on an iron catalyst following the zinc reduction method (Slota et al., 1987). The graphite was then pressed to produce a "target," which was then subject to AMS dating. The ^{14}C age mean and 1 standard deviation were calculated using the Libby half-life (5568 yr), following the conventions of (Stuiver and Polach, 1977). Calibration of the ^{14}C dates was undertaken using the IntCal013 calibration curve (Reimer et al., 2013). All calibrated ^{14}C ages are given at +/-95.4%, i.e. +/-2σ probability.
A reservoir effect could be present in the dated samples, as high $\delta^{15}N$ values, especially among the Neolithic population, could suggest possible fish consumption (see below). Previous studies on the reservoir effect in the Samara region of the southwestern Russia, northern Caucasus and Ukraine regions found ca. 400 year reservoir effect in dated individuals linked to fish consumption (Anthony, 2007; Lillie et al., 2009; Shishlina et al., 2009). The studies by Svyatko et al. (2015) in northeastern Kazakhstan suggest a possible reservoir effect of up to 300 years in Chalcolithic samples. On the other hand, Svyatko et al. (2009) and Marchenko et al. (2015) found no evidence for a reservoir effect in Chalcolithic and Bronze Age human samples from the Minusinsk Basin in Siberia and the Baraba forest-steppe in southwest Siberia. Such results call for checking the presence of any reservoir effect on a site-by-site basis.

5. Results and discussion

In total, 58 of the 68 humans (85.3 % success rate) and 45 animal (100% success rate) samples produced collagen with C:N values within the acceptable quality range of 2.9-3.6 (DeNiro, 1985). The other human and faunal data used in this publication was borrowed from already published sources by Motuzaite Matuzeviciute et al. (2015) and Ventresca Miller et al. (2013). In total, 85 human and 96 faunal remains were statistically analysed in this publication, excluding one human outlier Al_30 from the Neolithic Firsovo-XI site with $\delta^{13}C$ values of -15.3‰ and $\delta^{15}N$ values of 11.46‰. The dating of this sample has shown that the individual belongs to the Early Iron Age period (166-26 cal BC) (Table 1). In faunal data analysis, the outliers of Kz30F, Kz32F, Kz33F, belonging probably to beavers, were excluded from the statistical study. The $\delta^{13}C$ values of 3 analysed individuals range between -21‰ and -19.9‰, while the $\delta^{15}N$ values range between 4 and 3.5‰. Such low $\delta^{15}N$ values indicate that beavers were exploiting water-rich river or lake shores where plants were not drought-stressed. The fox, wolf and dog samples were also excluded from the statistical analysis, as their respective sample sizes were too small for reliable use. The $\delta^{13}C$ values of six carnivores (Kz31F, Kz08F, Al13F, GM65F, GM64F, GM63F) range between -22.3‰ and -17.3‰, while $\delta^{15}N$ values range between 12.3‰ and 9.6‰. The information on faunal data is presented in Table 2, Fig.2 (all faunal data is described in detail in SOM 1-a), on humans in Table 3, Fig.3 (all human data in detail is described in SOM 1-b) and the statistical outputs in Table 4.

5.1 Faunal results

The faunal data comprises of 24 individuals attributed to the Neolithic/Chalcolithic period and 72 individuals to the Bronze Age period. Firstly, the faunal samples from the Neolithic (Tavdinsky Grotto and Belkargaly-1) were compared to the Chalcolithic period (Botai-I, Kozhai-1, Belkargaly-1 sites). The statistical results have shown no difference in faunal isotopic results, the $\delta^{13}C$ values (Student's t-test, $p = 0.6897$) and $\delta^{15}N$ values (Student's t-test, $p = 0.8941$) (Table 4, output 1).

This results allowed us to combine both Neolithic and Chalcolithic herbivore fauna bone collagen results and compare them to the Bonze Age herbivore bone collage analysis results. A comparison of Neolithic/Chalcolithic herbivores ($\delta^{13}C$ mean value 19.6‰ and $\delta^{15}N$ values 6‰) against the Bronze Age herbivores ($\delta^{13}C$ mean value 19.5‰ and $\delta^{15}N$ values 6.3‰) shows that there is no significant difference by period in both $\delta^{13}C$ values (Student's t-test, $p = 0.7993$), and $\delta^{15}N$ values (t-test, $p = 0.8941$) (see Table 4, output 2, Fig. 2).

The outcome of the statistical test is very significant for answering one of the raised questions of the paper, which is to understand whether the climatic change during the Bronze Age left any significant impact on herbivore isotopic signal. The results have shown that the vegetation cover has not changed significantly to reflect in the stable isotope signal of herbivore collagen, as the average of both $\delta^{13}C$ and $\delta^{15}N$ values remain steady from the Neolithic through the Bronze Age.

5.2 Human results

The human data has been collected from four Neolithic sites (n-27), one site from the transition period from the Neolithic to the Chalcolithic (n-13) and from four Bronze Age sites (n-45).

The oldest Neolithic samples are coming from the Itkul (Bolshoi Mys) site. Two individuals from this site resulted in a radiocarbon age ranging from 5614-5342 cal BC. For the Neolithic/Chalcolithic period the average human-faunal offset values are only 0.1‰ in $\delta^{13}C$ and even 7.8‰ in $\delta^{15}N$, suggesting that people consumed high amounts of aquatic foods with a longer food chain (Hedges and Reynard 2007). A similar situation was observed from the Bronze Age period where the average human-faunal offset values are -0.4‰ in $\delta^{13}C$ and 5.5‰ in $\delta^{15}N$.

Radiocarbon dates received for this paper from 10 dated individuals range between *ca.* 5700 to 3700 cal BC for the Neolithic/Chalcolithic periods and between *ca.* 2500 to 2200 cal. BC for the Early Bronze Age period (Table 1). As one of the oldest radiocarbon dates received from dating human collagen are also correlated with the highest $\delta^{15}N$ values, reaching as high as 15.9‰ from all the dated individuals, this is not only an indication of a high consumption of fish (Hedges and Reynard 2007), but also probably evidence for the presence of a reservoir effect on the dating results following the Cook et al. (2002) model. According to Svyatko et al. (2015) the region of northern Kazakhstan for the Chalcolithic-Bronze Age individuals could have a reservoir age of ca. 300 years. For the sites under study in this paper, however, the reservoir effect has to be calculated separately for each site, as at the other sites of southwest Siberia, such as Preobrazhenka 6, a reservoir effect was not detected (Marchenko et al., 2015).

The Neolithic/Chalcolithic humans (n-40) from five sites in southwest Russia have a mean $\delta^{13}C$ value of -21.8±1.1‰, and a mean $\delta^{15}N$ value of 13.8±0.9‰. The Bronze Age humans (n-45) from four sites in the north of Kazakhstan and southwest Siberia have a mean $\delta^{13}C$ value of -19±0.6‰, and a mean $\delta^{15}N$ value of 11.8±1‰. A comparison of the Neolithic humans with Chalcolithic humans shows that there is no significant difference between them in $\delta^{13}C$ (Student's t-test, $p = 0.053$), and in $\delta^{15}N$ (Student's t-test, $p = 0.678$) (Table 4, output 3). After combining Neolithic and Chalcolithic human mean values and comparing them with the Bonze Age humans, significant differences in both $\delta^{13}C$ and $\delta^{15}N$ are seen. The mean $\delta^{13}C$ values for Neolithic/Chalcolithic humans = -21.8±1.1‰ and for Bronze Age humans = -19±0.6‰, respectively: $p = <0.000$), and in $\delta^{15}N$ (mean $\delta^{15}N$ = 13.8±0.9‰ and 11.8±1‰, respectively: $p = 0.000$) (Table 4; output 5, Fig. 3). Despite the small sample size, humans from the Neolithic/Chalcolithic of the Tuzovskye Bugry-I (n-13) were compared with humans of the Early Bronze Age site Teleutsky Vzvoz-I (n-4). The results of Student's statistical t-test showed a significant difference between the populations of those two sites of different periods ($\delta^{13}C$ values: p=0.000; $\delta^{15}N$ values: p=0.000) (Table 4; output 6), indicating a visible transition to pastoralism starting from the Early Bronze Age.

In analysis, the lack of difference in both $\delta^{13}C$ and $\delta^{15}N$ values between animals of the Neolithic/Chalcolithic periods and the Bronze Age periods, coupled with the significant statistical differences between humans of these periods indicates that climatic fluctuation did not have any influence on the animal isotopic signatures though time. The animals, especially ruminants, grazing in a variety of ecological niches (Shishlina et al., 2012) averaged out their isotopic signature which does not differ significantly though time, despite a potential vegetation change and the possible change of plant $\delta^{13}C$ and $\delta^{15}N$ values due to aridity and increased salinity (e.g. Flohr et al., 2011; Heaton 1987).

A significant difference in both $\delta^{13}C$ and $\delta^{15}N$ values between Neolithic/Chalcolithic and Bronze Age humans shows a significant shift in human diet seen in the Early Bronze Age period. The increase in $\delta^{13}C$ values up to -2.8‰ is probably linked with the beginning of cattle breeding in the region and the increased consumption of animals that grazed on mixed C3/C4 vegetation, while during the Neolithic people were instead probably exploiting more aquatic animals. The reduction in $\delta^{15}N$ values in the Bronze Age by up to 2‰ shows a drop in the trophic level and a possible reduction of fish consumption. The reduction in food diversity among humans during the Bronze is probably the main reason of isotope value change. This is well illustrated in the Figure 4 where the Neolithic/Chalcolithic individuals are much wider distributed than the Bonze Age ones, that cluster closer above the isotopic results received from fauna. Noteworthy, the dietary change in the Bronze Age individuals appears to coincide roughly with the earliest evidence for ovicaprids in the region (second half of the 3rd mill. cal BC) (Kiryushin et al. 2005), that might imply quite rapid transition to different diet and economy. Further studies might be able to clarify if the first pastoralists in the region under study were local populations that adapted to pastoralism or people who migrated into these territories with their stock.

According to stable isotope data, the dietary shift in humans of southwest Siberia is visible from the Early Bronze Age period (second half of the 3rd mil. cal BC). However, looking at the published isotopic data of two humans from Chalcolithic sites in northern Kazakhstan (Botai) and central Kazakhstan (Karagash) their values are very similar to the ones of the Bronze Age periods (Karagash human: $\delta^{13}C$ value is -18.2‰ and $\delta^{15}N$ is 12.6‰ (Motuzaite Matuzeviciute 2015); Botai human: $\delta^{13}C$=-18.1‰; $\delta^{15}N$=12.4‰ (O'Connell et al. 2003)). As mentioned earlier, the Karagash burial is attributed to the early wave of the Yamnaya Culture, contained the earliest evidence of domesticated sheep in the region, while the Botai site contained the earliest evidence of horse domestication (Outram et al., 2011). Both sites are dated between 3500-2700 cal BC (Outram et al. 2009; Motuzaite Matuzeviciut et al. 2015). Therefore, despite the small sample size, one can infer that the processes of transition to pastoralism visible in human isotope data started earlier in the south (central/northern Kazakhstan) than in the north (southwest Siberia).

6. Conclusions

The stable isotope data of human and animal collagen from the Neolithic/Chalcolithic though the Bronze Age periods of southwest Siberia have demonstrated a significant human dietary change, with a concurrent continuity in the diet of herbivore animals. The results indicate that climatic variation did not pay a role in the isotopic ratios of fauna throughout the time periods studied. The reduction in food diversity among humans during the Bronze Age is probably the main reason of isotope value change. The increase in $\delta^{13}C$ values and the reduction in $\delta^{15}N$ values starting from the Early Bronze Age period in southwest Siberia indicate an increased consumption of animal products that grazed on a mixed C3/C4 environment, and a concurrent reduction of fish consumption. The high $\delta^{15}N$ values in both Neolithic/Chalcolithic as well as Bronze Age humans could also indicate the presence of a reservoir effect within the dated individuals. However, this has to be tested on the site by site basis.
The human dietary change during the second half of the 3rd mil. cal BC is linked with the establishment of pastoralism in southwest Siberia and the introduction of south-western Asian animal species into the region. However, the processes of pastoralism further south in Kazakhstan may have started earlier during the early third millennium BC. The research results allow us to conclude that the processes of long distance East-West interaction took place though southwest Siberia more or less during a similar period as along the Inner Asian Mountain Corridor in southern Central Asia.

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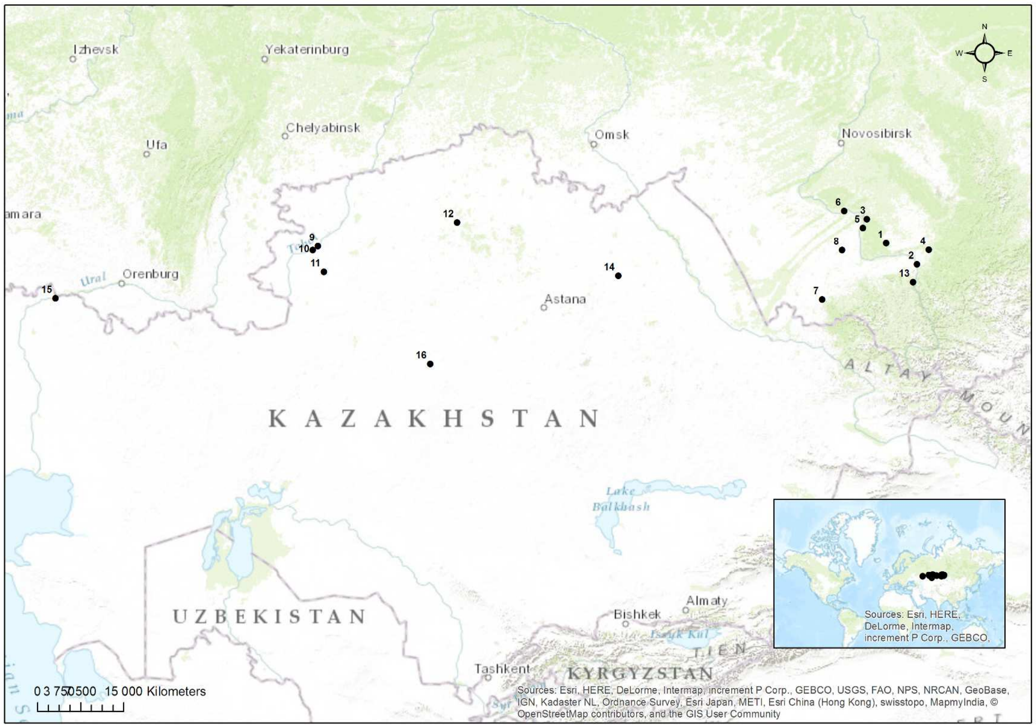
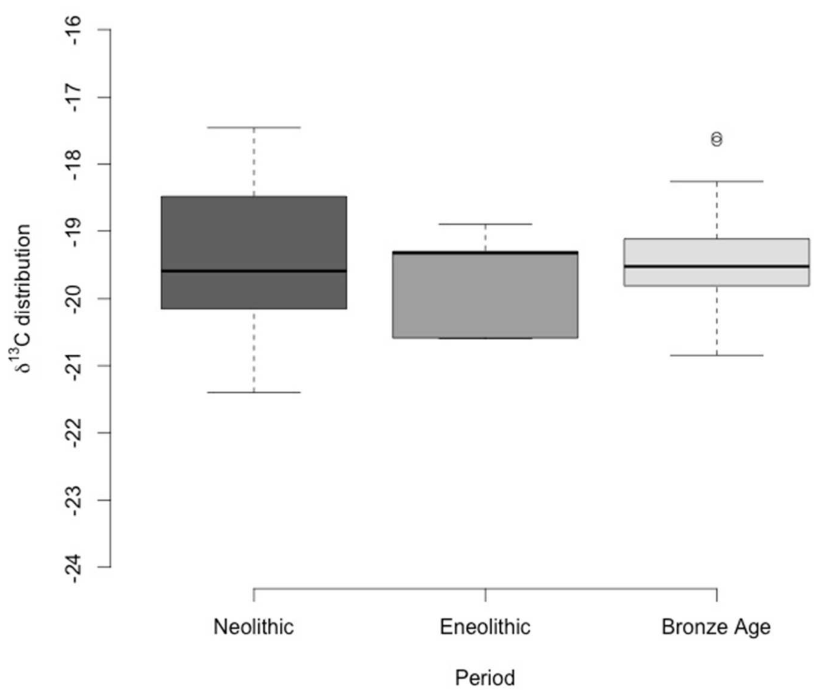
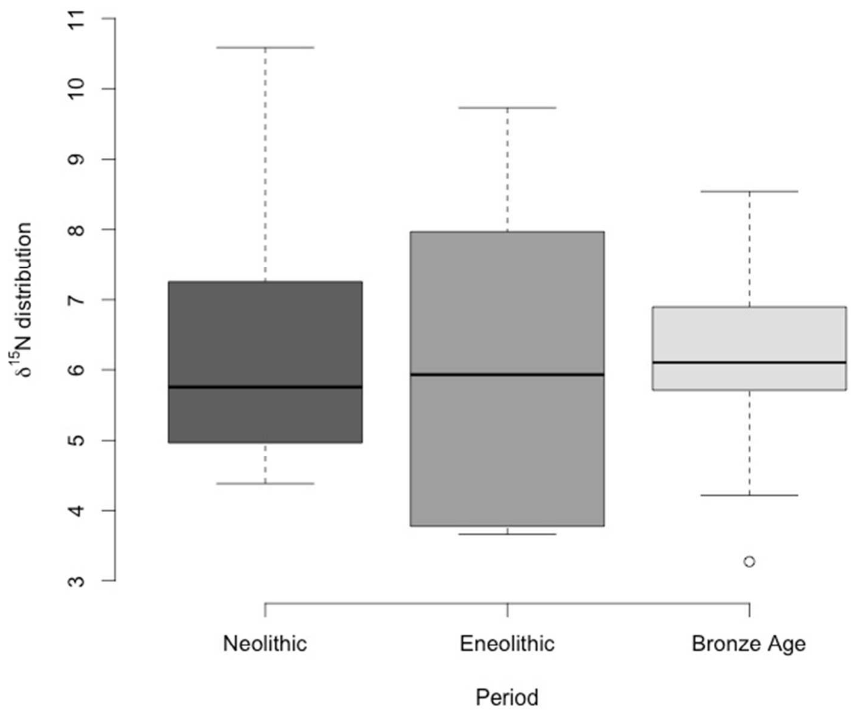


Figure 1. The location of the sites analysed in this paper. 1. Itkul (Bolshoi Mys); 2, Ust-Isha; 3, Firsovo-XI,XIV; 4. Solontsy-5; 5. Tuzovskye Bugry-I; 6. Teleutsky Vzvoz -I; 7. Kolyvanskoye-I; 8. Berezovaya Luka; 9. Novoilinovka; 10. Lisakovsk; 11. Belkaragai-1; 12. Botai-I; 13. Tavdinsky Grotto; 14. Bozshakol-6; 15. Kirik-Oba-1; 16. Kozai-1.

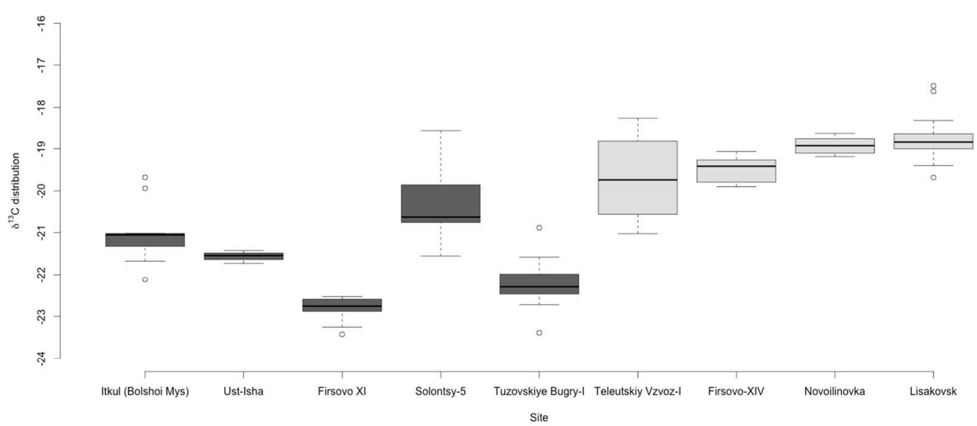


A

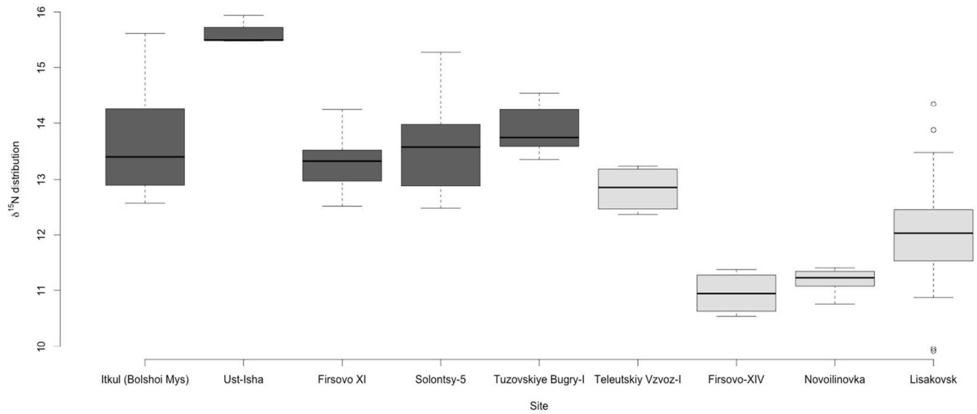


B

Fig. 2 The boxplot showing the δ ^{13}C (A) and δ ^{15}N (B) values of the Neolithic/ Eneolithic (Chalcolithic) and Bronze Age herbivore animals from the southwest Siberia and northern Kazakhstan.



A



B

Fig. 3 The boxplot showing the δ ^{13}C (A) and δ ^{15}N (B) values of Bronze Age humans from the southwest Siberia and northern Kazakhstan. Darker color indicates the Neolithic-Chalcolithic humans while lighter color - the Bronze Age humans. The human data from the north Kazakhstan is supplemented by Mouzaite Matuzeviciute et al. 2015; Ventresca-Miller et al. 2013.

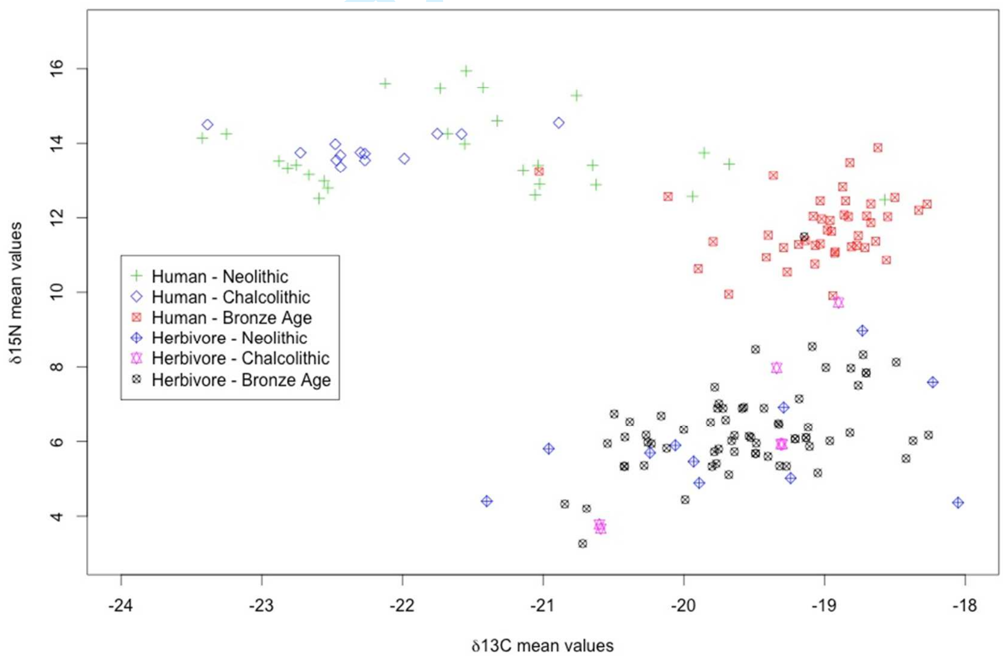


Fig. 4 ^{13}C (x) and δ ^{15}N (y) values of the Neolithic/Chalcolithic and Bronze Age herbivore animals and humans from the southwest Siberia and northern Kazakhstan.

Sample ID	Site name	Mean $\delta^{13}C_{VPDB}$ (‰)	Mean $\delta^{15}N_{AIR}$(‰)	^{14}CHRONO Lab code	^{14}C Age	±	AMS $\delta^{13}C$	cal BC 95.4 (2 σ)	Period
Al_01	Itkul (Bolshoi Mys)	-19.68	15.94	UBA-22950	6470	40	-19.1	5510–5342	Neolithic
Al_09	Itkul (Bolshoi Mys)	-22.12	15.60	UBA-22951	6577	35	-20.9	5614–5478	Neolithic
Al_13	Ust-Isha	-21.55	15.94	UBA-22952	5114	47	-20	4035–3792	Neolithic
Al_30	Firsovo-XI	-15.30	11.46	UBA-22953	2044	34	-14.8	166–26	Early Iron Age
Al_38	Firsovo-XI	-23.25	14.24	UBA-22954	6684	39	-19.8	5667–5531	Neolithic
Al_51	Solontsy-5	-18.57	12.48	UBA-22954	6354	41	-16	5469–5224	Neolithic
Al_53	Solontsy-5	-21.56	13.98	UBA-22956	5081	38	-22.4	3965–3792	Neolithic/Chalcolithic
Al_22	Tuzovskiye Bugry-I	-23.30	13.75	UBA-22957	5004	36	-19.3	3943–3701	Neolithic/Chalcolithic
Al_40	Firsovo-XIV	-19.90	10.63	UBA-22958	3311	34	-19.4	1684–1512	Middle Bronze Age
Al_45	Teleutsky Vzvoz-I	-19.36	13.13	UBA-22959	3837	33	-18.7	2459–2200	Early Bronze Age

TABLE 1: ^{14}C dates, δ^{13}C and δ^{15}N values of humans from Russia. Radiocarbon data calibrated against the IntCal13 calibration curve (Reimer et al. 2013)

Species (n)	$\delta^{13}C_{VPDB}$ (‰)					$\delta^{15}N_{AIR}$(‰)				
	Max	Min	Mean	Sd	Median	Min	Max	Mean	Sd	Median
Neolithic-Chalcolithic fauna										
Big mammal (11)	-17.5	-21	-19.3	0.9	-19.3	4.9	10.6	7.3	1.7	6.9
Horse (4)	-18.5	-20.6	-19.6	1.2	-20	3.7	5.9	4.6	1	4.1
Roe deer (3)	-21.4	-19.2	-20.2	1.1	-19.3	4.4	5.5	4.9	0.5	5
Beaver (3)	-20.9	-20.9	-20.4	0.5	-20.3	4	3.8	3.9	0.1	3.8
Dog/wolf/fox (3)	-18.2	-22.3	-19.9	2.2	-19	11.6	9.6	10.5	1	10.5
Bronze Age fauna										
Sheep/goat (28)	-17.6	-19.8	-19	0.5	-19.1	8.5	3.3	6.1	1.1	6
Cattle (24)	-18.4	-20.7	-19.5	0.5	-19.6	5.1	8.8	6.7	1.0	6.6
Horses (15)	-19.3	-20.9	-20.3	0.4	-20.3	6.9	4.2	6	0.8	6.1
Dogs (3)	-17.7	-19	-18.3	0.6	-18.1	12.3	9.3	10.6	1.5	10.3
Saiga antelope (1)	-20.4	-20.4	-20.4			5.3	5.3	5.3		
Sus sp. (1)	-19.6	-19.6				3.2	3.2			

Table 2: Summary of $\delta^{13}C$ and $\delta^{15}N$ values of faunal samples from the Neolithic/Chalcolithic and Bronze Age of the south-western Siberia and northern Kazakhstan

Site name (per site-n)	Period (total-n)	$\delta^{13}C_{VPDB}$ (‰)					$\delta^{15}N_{AIR}$(‰)				
		Min	Max	Mean	Sd	Median	Min	Max	Mean	Sd	Median
Neolithic/Chalcolithic											
	Neolithic/Chalcolithic (40)	**-23.4**	**-18.6**	**-21.8**	**1.1**	**-21.9**	**12.5**	**15.9**	**13.8**	**0.9**	**13.6**
Itkul (Bolshoi Mys) (9)	Neolithic	-22.1	-19.7	-21	0.8	-21.1	12.6	15.6	13.4	0.5	13.3
Ust-Isha (3)	Neolithic	-21.7	-21.4	-21.6	0.2	-21.6	15.5	15.9	15.6	0.3	15.5
Firsovo-XI (9)	Neolithic	-23.4	-22.5	-22.8	0.3	-22.8	12.5	14.2	13.3	0.6	13.3
Solontsy-5 (6)	Neolithic	-21.6	-18.6	-20.3	1	-20.6	12.5	15.7	13.6	1	13.6
Tuzovskiye Bugry-I (13)	Neolithic/ Chalcolithic	-23.4	-20.9	-22.2	0.6	-22.3	13.4	14.6	13.9	0.4	13.6
Bronze Age											
	Bronze Age (45)	**-21.3**	**-17.5**	**-19**	**0.6**	**-18.9**	**9.9**	**14.4**	**11.8**	**1**	**11.7**
Novoilinov-ka (8)	Bronze Age	-21.2	-18.6	-18.9	0.2	-18.9	11.2	11.4	10.8	0.2	11.2
Lisakovsk (28)	Bronze Age	-19.7	-17.5	-18.8	0.4	-18.8	9.9	14.4	12.0	1.0	12.0
Teleutsky Zvoz-I (4)	Bronze Age	-21.03	-18.3	-19.7	1.2	-19.7	12.4	13.2	12.8	0.4	12.9
Firsovo-XIV (5)	Bronze Age	-19.9	-19	-19.5	0.3	-19.4	10.5	11.4	11	0.4	10.9

Table 3: Summary of $\delta^{13}C$ and $\delta^{15}N$ values of human samples from southern Siberia. Novoilinovka data was taken from Motuzaite Matuzeviciute et al. (2015) and Lisakovsk from Ventresca Miller et al. (2014).

Table 4: Results of statistical Student's t-test

	n	$\delta^{13}C$	$\delta^{15}N$
Comparison		*p* value	*p* value
Statistical tests outputs of fauna			
1. Neolithic vs Chalcolithic herbivores	19	0.6897	0.8941
2.Neolithic+Eneolithic vs Bronze Age herbivores	87	0.7993	0.5051
Statistical tests outputs of human data			
3. Neolithic vs Chalcolithic 4th mill. BC humans	40	0.053	0.6782
4. Neolithic/Chalcolithic humans vs Bronze Age humans	85	0.0000	0.0000
5. Chalcolithic vs Bronze Age	58	0.0000	0.0000
6. Tuzovskie Bugry-I (Neolithic-Chalcolithic vs Teleutsky Vzvoz-I (Early Bronze Age)	17	0.000	0.000

KZ03F	Kozhai-1	-18.23	7.59	3.16	BIG MAMMAL (H(
KZ04F	Belkaragai-1	-17.46	10.59	3.24	BIG MAMMAL (H(
KZ06F	Kozhai-1	-18.73	8.98	3.28	BIG MAMMAL (H(
KZ23F	Botai-I	-18.90	9.73	3.12	BIG MAMMAL (H(
KZ29F	Botai-I	-19.34	7.97	3.09	BIG MAMMAL (H(
KZ25F	Botai-I	-19.31	5.93	3.14	BIG MAMMAL (H(
KZ26F	Botai-I	-20.60	3.78	3.16	Equs
KZ27F	Botai-I	-19.30	5.93	3.11	Equs
KZ28F	Botai-I	-20.59	3.67	3.16	Equs
KZ07F	Belkaragai-1	-20.06	5.90	3.49	BIG MAMMAL (H(
SS1F	Tavdinsky Grotto	-19.89	4.90	3.21	BIG MAMMAL (PF
SS2F	Tavdinsky Grotto	-19.93	5.47	3.19	ROE DEER, CAPRA
SS3F	Tavdinsky Grotto	-20.24	5.70	3.21	BIG MAMMAL/ho
SS4F	Tavdinsky Grotto	-19.24	5.03	3.19	roe-deer OR MOU
SS5F	Tavdinsky Grotto	-18.05	4.38	3.19	hose
SS6F	Tavdinsky Grotto	-21.40	4.42	3.22	ROE DEER, CAPRA
SS7F	Tavdinsky Grotto	-20.96	5.81	3.12	BIG MAMMAL
SS8F	Tavdinsky Grotto	-19.29	6.92	3.24	BIG MAMMAL
KZ30F	Botai-I	-20.34	3.82	3.13	beaver
KZ32F	Botai-I	-19.94	3.83	3.10	beaver
KZ33F	Botai-I	-20.92	4.01	3.23	beaver or similar
KZ31F	Botai-I	-18.22	9.58	3.13	fox
KZ08F	Kozhai-1	-19.04	11.55	3.16	dog/wulf
AlF_13	Tuzovskiye Bugry	-22.30	10.47	3.33	dog
GM_F09	Bozshakol-6	-18.99	7.98	3.47	caprine
GM_F43	Bozshakol-6	-18.42	5.55	3.16	caprine
GM_F44	Bozshakol-6	-18.76	7.51	3.13	caprine
GM_F45	Bozshakol-6	-19.09	8.54	3.38	caprine
GM_F46	Bozshakol-6	-17.60	7.09	3.16	caprine
GM_F47	Bozshakol-6	-18.81	7.96	3.18	caprine
GM_F48	Bozshakol-6	-19.32	5.35	3.17	caprine
GM_F49	Bozshakol-6	-18.73	8.32	3.18	caprine
GM_F50	Bozshakol-6	-19.14	11.50	3.14	caprine
GM_F51	Bozshakol-6	-18.26	6.17	3.15	caprine
GM_F8	Bozshakol-6	-19.18	7.15	3.42	caprine
GM_F79	Lisakovsk	-18.70	7.84	3.16	caprine
GM_F79	Lisakovsk	-18.70	7.84	3.16	caprine
GM_F80	Lisakovsk	-19.80	5.34	3.15	caprine
GM_F82	Lisakovsk	-19.13	6.10	3.14	caprine
GM_F82	Lisakovsk	-19.13	6.10	3.14	caprine
GM_F83	Lisakovsk	-19.21	6.07	3.16	caprine
GM_F83	Lisakovsk	-19.21	6.07	3.16	caprine
GM_F84	Lisakovsk	-18.82	6.24	3.53	caprine
GM_F85	Lisakovsk	-19.48	5.96	3.20	caprine

GM_F86	Lisakovsk	-19.49	5.68	3.22	caprine
GM_F86	Lisakovsk	-19.49	5.68	3.22	caprine
GM_F101	Lisakovsk	-19.77	5.41	3.52	cow
GM_F102	Lisakovsk	-19.81	6.52	3.56	cow
GM_F87	Lisakovsk	-19.75	5.80	3.59	cow
GM_F89	Lisakovsk	-19.78	5.73	3.60	cow
GM_F90	Lisakovsk	-19.75	7.02	3.65	cow
GM_F95	Lisakovsk	-19.40	5.61	3.48	cow
GM_F96	Lisakovsk	-19.27	5.34	3.19	cow
GM_F97	Lisakovsk	-19.70	6.59	3.15	cow
GM_F98	Lisakovsk	-19.54	6.14	3.67	cow
GM_F99	Lisakovsk	-19.11	5.87	3.58	cow
GM_F105	Kenelkel-18	-19.68	5.12	3.22	cow
GM_F65	Bozshakol-6	-17.70	12.25	3.55	dog
GM_F64	Bozshakol-6	-18.14	10.27	3.14	dog
GM_F63	Bozshakol-6	-18.96	9.30	3.13	dog
GM_F94	Lisakovsk	-20.12	5.82	3.16	horse
GM_F93	Lisakovsk	-20.42	6.12	3.50	horse
GM_F91	Lisakovsk	-20.38	6.53	3.45	horse
GM_F75	Bozshakol-6	-20.16	6.69	3.52	horse
GM_F74	Bozshakol-6	-20.27	6.17	3.17	horse
GM_F73	Bozshakol-6	-20.69	4.21	3.45	horse
GM_F71	Bozshakol-6	-20.28	5.36	3.41	horse
GM_F69	Bozshakol-6	-20.49	6.75	3.50	horse
GM_F68	Bozshakol-6	-19.76	6.90	3.47	horse
GM_F67	Bozshakol-6	-20.26	5.98	3.22	horse
GM_F66	Bozshakol-6	-20.54	5.95	3.41	horse
GM_F10	Bozshakol-6	-19.32	6.46	3.44	horse
GM_F100	Lisakovsk	-20.85	4.34	3.19	horse
GM_F07	Kirik-Oba-II	-20.00	6.32	3.14	horse
GM_F06	Kirik-Oba-II	-20.23	5.94	3.19	horse
GM_F81	Lisakovsk	-20.42	5.34	3.68	saiga
KZ13F	Novoilinovka	-19.64	6.16	3.24	sus. Sp.
KZ16F	Novoilinovka	-19.78	7.46	3.16	Ovicapride
KZ20F	Novoilinovka	-19.64	5.73	3.42	CATTLE
KZ21F	Novoilinovka	-19.99	4.46	3.22	BIG MAMMAL (H(
KZ09F	Novoilinovka	-19.43	6.90	3.15	Cattle
KZ10F	Novoilinovka	-19.66	6.02	3.17	BIG MAMMAL (H(
KZ11F	Novoilinovka	-19.49	8.46	3.19	BIG MAMMAL (H(
AlF_01	Teleutsky Vzvoz-I	-18.96	6.02	3.16	sheep
AlF_02	Teleutsky Vzvoz 1	-19.52	6.11	3.19	cattle
AlF_03	Teleutsky Vzvoz-I	-18.37	6.02	3.23	cattle
AlF_04	Teleutsky Vzvoz-I	-19.58	6.90	3.21	cattle
AlF_05	Teleutsky Vzvoz-I	-19.72	6.90	3.21	sheep/goat 1

AlF_06	Teleutsky Vzvoz-I	-19.33	6.49	3.22	sheep/goat 2
AlF_07	Kolyvanskoye-I	-20.72	3.27	3.18	cattle 1
AlF_08	Kolyvanskoye-I	-19.12	6.39	3.16	cattle 2
AlF_09	Kolyvanskoye-I	-17.66	5.71	3.18	sheep/goat 3
AlF_10	Berezovaya Luka	-19.05	5.17	3.15	sheep/goat 1
AlF_11	Berezovaya Luka	-19.57	6.93	3.14	cattle 2
AlF_12	Berezovaya Luka	-18.49	8.12	3.12	cattle 3
GM_F81	Lisakovsk	-20.42	5.34	3.68	saiga
KZ13F	Novoilinovka	-19.64	6.16	3.24	sus. Sp.

* outliers are marked in green

Neo-Chal
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Neo-Chal
Chalcolithic
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Early Bronze
Early Bronze
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Early Bronze
Early Bronze Age (Eluninskaya culture)
Early Bronze Age (Eluninskaya culture)
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Early Bronze Age (Eluninskaya culture)
Early Bronze Age (Eluninskaya culture)
Early Bronze Age (Eluninskaya culture)
Early Bronze Age (Eluninskaya culture)
Middle Bronze Age

Identifier 1	Site	Period	mean d13C	Mean d15N
AI_01	Itkul (Bolshoi Mys)	Neolithic	-19.68	13.44
AI_2A	Itkul (Bolshoi Mys)	Neolithic	-21.02	12.90
AI_02B	Itkul (Bolshoi Mys)	Neolithic	-21.06	12.61
AI_03	Itkul (Bolshoi Mys)	Neolithic	-21.68	14.26
AI_04	Itkul (Bolshoi Mys)	Neolithic	-19.94	12.57
AI_05	Itkul (Bolshoi Mys)	Neolithic	-21.33	14.59
AI_07	Itkul (Bolshoi Mys)	Neolithic	-21.14	13.27
AI_08	Itkul (Bolshoi Mys)	Neolithic	-21.04	13.40
AI_09	Itkul (Bolshoi Mys)	Neolithic	-22.12	15.60
AI_13	Ust-Isha	Neolithic	-21.55	15.94
AI_15	Ust-Isha	Neolithic	-21.73	15.47
AI_16	Ust-Isha	Neolithic	-21.43	15.49
AI_31	Firsovo-XI	Neolithic	-22.82	13.33
AI_32	Firsovo-XI	Neolithic	-22.59	12.51
AI_33	Firsovo-XI	Neolithic	-22.88	13.52
AI_34	Firsovo-XI	Neolithic	-23.42	14.14
AI_35	Firsovo-XI	Neolithic	-22.67	13.15
AI_36	Firsovo-XI	Neolithic	-22.76	13.42
AI_37	Firsovo-XI	Neolithic	-22.56	12.97
AI_38	Firsovo-XI	Neolithic	-23.25	14.24
AI_39	Firsovo-XI	Neolithic	-22.53	12.79
AI_50	Solonts-5	Neolithic	-19.86	13.74
AI_51	Solonts-5	Neolithic	-18.57	12.48
AI_52	Solonts-5	Neolithic	-20.76	15.27
AI_53	Solonts-5	Neolithic	-21.56	13.98
AI_54	Solonts-5	Neolithic	-20.65	13.41
AI_55	Solonts-5	Neolithic	-20.62	12.88
AI_17	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-21.75	14.25
AI_18	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-22.27	13.54
AI_19	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-22.27	13.72
AI_20	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-22.44	13.68
AI_21	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-22.48	13.97
AI_22	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-22.30	13.75
AI_23	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-21.58	14.24
AI_24	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-21.99	13.59
AI_25	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-20.89	14.55
AI_26	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-22.47	13.55
AI_27	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-22.44	13.36
AI_28	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-23.39	14.50
AI_29	Tuzovskiye Bugry-I	Neolithic/Chalcolithi	-22.73	13.75
AI_45	Teleutsky Vzvoz-I	Early Bronze (Elunins	-19.36	13.13
AI_46	Teleutsky Vzvoz-I	Early Bronze (Elunins	-20.11	12.56
AI_47	Teleutsky Vzvoz-I	Early Bronze (Elunins	-21.03	13.24

Al_49	Teleutsky Vzvoz-I	Early Bronze (Elunins	-18.27	12.36
Al_40	Firsovo- XIV	Middle Bronze (Andr	-19.90	10.63
Al_41	Firsovo- XIV	Middle Bronze (Andr	-19.79	11.37
Al_42	Firsovo- XIV	Middle Bronze (Andr	-19.41	10.94
Al_43	Firsovo- XIV	Middle Bronze (Andr	-19.07	11.27
Al_44	Firsovo- XIV	Middle Bronze (Andr	-19.27	10.54
KZ18	Novoilinovka	Middle Bronze (Sinta	-18.64	11.38
KZ19	Novoilinovka	Mid Bronze (Sintasht	-19.07	10.76
KZ20	Novoilinovka	Mid Bronze (Sintasht	-19.14	11.40
KZ21	Novoilinovka	Mid Bronze (Sintasht	-18.71	11.21
KZ22	Novoilinovka	Mid Bronze (Sintasht	-18.93	11.05
KZ23	Novoilinovka	Mid Bronze (Sintasht	-18.92	11.10
KZ24	Novoilinovka	Mid Bronze (Sintasht	-18.81	11.23
KZ25	Novoilinovka	Mid Bronze (Sintasht	-19.18	11.29
Al_30	Firsovo-XI	IRON AGE	-15.30	11.46

Mean C/N	Burial ID	Gender ID
3.23	grave 1	
3.24	grave 2	
3.20	grave 2	
3.18	grave 3	
3.20	grave 4	
3.25	grave 4	
3.19	grave 11	
3.18	grave 12	
3.19	grave 13	
3.21	burial 8 (3267)	
3.40	burial 10 (3269)	
3.25	burial 11 (3270)	
3.21	grave 41	F
3.25	grave 14, skeleton 1	F
3.23	grave 42	M
3.24	grave 15/3	M
3.25	grave 9	M
3.26	grave 17	F
3.26	grave 14, skeleton 2	F
3.21	grave 15, skull 3	F
3.26	grave 18	M
3.17	Grave 1	
3.17	grave 4	
3.20	grave 7	
3.24	grave 9	
3.19	grave 3	
3.27	grave 2	
3.29	grave 7, skeleton 2	F
3.24	grave 10	F
3.19	grave 9	M
3.32	grave 3	M
3.23	grave 8	M?
3.22	grave 27	F
3.21	grave 32	M
3.22	grave 4	M
3.21	grave 24	F
3.24	grave 2	M
3.34	grave 7, skeleton 1	M
3.28	grave 33, skeleton 1 (4)	M
3.21	grave 33, skeleton 2 (5)	F
3.26	grave 26	M
3.22	grave 10	M
3.31	grave 7	M

3.24	grave 22	F	
3.19	grave 40	F	
3.17	grave 25	M	
3.18	grave 7(1)	M	
3.17	grave 7 (2)	F	
3.17	grave 14	F	
3.13	Kurgans 3/grave 3		
3.11	Kurgan 2/grave 2		
3.20	Kurgan 2/grave 2		
3.12	Kurgan 2/ garve 2/2		
3.13	Kurgan 2/grave 2/1		
3.13	Kurgan 1/grave 2/1		
3.12	Kurgan 2/2		
3.16			
3.22	grave 16	F	outlier